P-24: Plasma Physics

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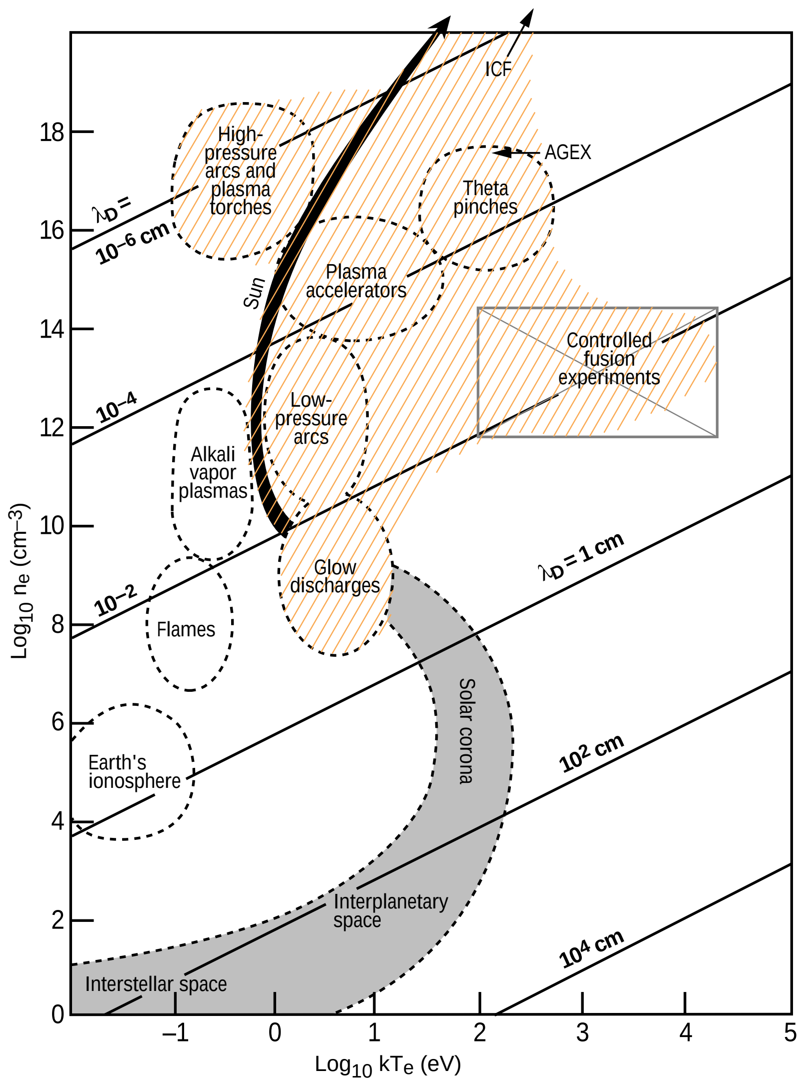
Fig. I-8. Range of plasma temperatures and densities. The orange shaded region shows the regime of P-24 research. λ_D defines the fundamental scale length for plasma interactions.



Introduction

The Plasma Physics Group (P-24) investigates the basic properties of plasmas with a view to applications in important Laboratory and national programs. Plasmas occur in nature when matter exceeds temperatures of roughly 10,000°C. At these temperatures, the constituent atoms and molecules of matter begin to lose their bound electrons to form a substance composed of positive or negative ions and free electrons. All principal phenomena in plasmas can be traced to the fact that ions and electrons interact with each other through long-range electromagnetic forces. The electromagnetic interactions of groups of charged particles are often coherent, leading to collective modes of plasma behavior. This collective interaction of charged particles, a many-body problem, is the essence of the field of plasma physics.

Roughly 99% of the matter in the universe is in a plasma state. Plasmas can exist over a large range of temperatures and densities (Fig. I-8). For example, interstellar space contains plasmas with densities of less than one ion or electron per cubic meter at a temperature exceeding 1,000°C. In contrast, plasmas created by intense laser compression of micropellets achieve densities of 10^{24} ions or electrons per cubic centimeter at temperatures exceeding 10,000,000°C. The understanding and application of such diverse plasmas forms the raison d'être of plasma physics, which is a Los Alamos National Laboratory (LANL) core competency.

P-24 is composed of a diverse technical staff with expertise in plasma physics, plasma chemistry, atomic physics, laser and optical science, and pulsed-high-power engineering. The group uses both on-site and off-site experimental facilities to address problems of national significance in inertial and magnetic fusion, nuclear-weapons stewardship, conventional defense, environmental management, and plasma-based advanced or green manufacturing. Our agenda includes basic research in the properties of energetic matter and applied research that supports the principal Los Alamos mission of reducing the nuclear danger. As shown in Fig. I-8 and discussed below, the pursuit of this agenda entails the physics of plasmas over a wide and diverse range of conditions.

P-24's WWW site (http://fjwsys.lanl.gov/) contains information on our group's organizational structure and research.

Trident Laser Facility

Trident is LANL's multipurpose laboratory for conducting experiments requiring high-energy laser-light pulses. It is operated primarily for Inertial Confinement Fusion (ICF) research, weapons physics, and basic research, and it serves both LANL and external users. Features include flexible driver characteristics and illumination geometries, a broad resident diagnostic capability, and flexible scheduling. A dedicated staff maintains and operates the facility and assists the experimenters.

The principal resource at Trident is the laser driver. It employs a neodymium-doped, yttrium-lithium-fluoride (Nd:YLF) master oscillator and a chain of Nd:phosphate glass rod and disk amplifiers in a conventional master-oscillator, power-amplifier (MOPA) architecture. The oscillator output pulse is temporally shaped, amplified, split into two beams, amplified again, frequency-doubled, transported, and focused to the target. A third beamline can be used as an optical probe or to provide an x-ray backlighting capability. Its pulse can be either 100 ps in length or the same length and shape as those of the main drive beams. Although the third beamline is normally operated at 527 nm, fundamental (1054 nm) output of this beamline can also be used directly in the target chamber. The third beam can be timed to become active before or up to 5 ns after the main drive beams. The output of the master oscillator may also be frequency-broadened and "chirped" before amplification to allow compression to subpicosecond pulse lengths. Compressed pulses are presently available at the 1- to 2-J level at a separate target chamber in the front end, and we are anticipating compression of higher-energy pulses in the future.

The main high-vacuum target chamber is a cylinder approximately 150 cm long and 75 cm in diameter (Fig. I-9). Single- or double-sided illumination of targets is possible through several 20-cm-diameter ports on each end of the chamber. More than 40 smaller ports are available for diagnostic instrumentation. Individual targets are inserted through an airlock. The target insertion and positioning mechanism provides *x-y-z* and rotation adjustment under computer control with 1-μm linear and 0.01° angular resolution. The three-axis target-viewing system has 20-μm resolution. The chamber is fitted with a Nova-standard six-inch manipulator (SIM) to accept all SIM-based instruments for checkout, characterization, or use. Although Trident is conveniently located in an "open" area of the Laboratory, the target room can be secured administratively for classified experiments.

Optical diagnostics include illumination and backscattered light calorimeters, backscattered light spectrometers, and high-bandwidth (5-GHz) and streak-camera-based power monitors. Target x-ray emission is monitored by filtered, photoconductive diamond detectors and an x-ray streak camera with <10-ps resolution. A Nova-standard, gated x-ray imager provides 16 gated, filtered x-ray images per nanosecond with a resolution of 80 ps. Various filtered x-ray power and spectral diagnostics can be installed as needed. These cover the energy range of 0–35 keV. Static x-ray pinhole cameras are also available. Most optical and target diagnostics are available for either the main target chamber or the ultrahigh-irradiance chamber.

Trident is available to Laboratory and outside experimenters. The quality of proposed research and its relevance to Laboratory missions are major criteria that the P-Division Trident Steering Committee considers in determining what experiments are fielded. Trident is operated by P-24 as a DOE user facility that principally

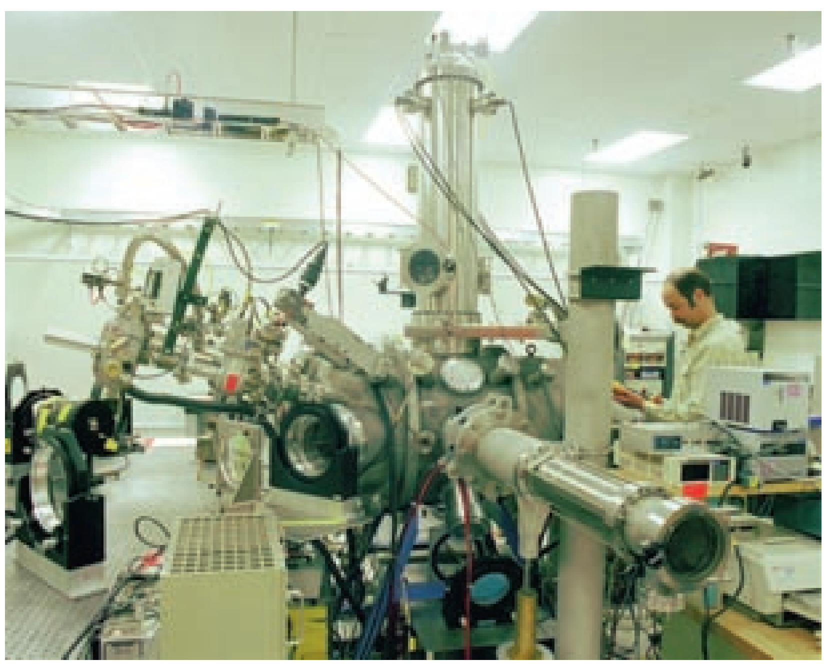


Fig. I-9. Target chamber of the Trident laser facility.

supports the ICF and Above-Ground Experiments (AGEX) programs. It is funded through and operated for the Nuclear Weapons Technology (NWT) ICF Program Office. The resources of the Laboratory's Target-Fabrication Facility, operated by the Materials Science and Technology (MST) Division, are also available to assist experimenters in designing, fabricating, and characterizing targets for Trident experiments.

We are actively pursuing a facility upgrade to the Trident laser that should occur in the next few years. As envisioned, the Trident Upgrade will be a flexible, high-shot-rate facility with the required performance for weapons-relevant research in materials properties and in the hydrodynamics of ionized matter. It will enhance the present Trident capabilities in experiments on laser-matter interactions and other fundamental-science topics. It will provide a staging capability to higher-energy-density facilities and will attract high-quality scientific research to stockpile stewardship.

For single-sided, long-pulse illumination, the Trident Upgrade will have similar capabilities to those of the world's two most powerful lasers, Omega and Nova, but with the capability of providing both classified shots and the use of special nuclear materials. In addition, the Trident Upgrade will function as a premier calibration, prototyping, and staging facility for the National Ignition Facility (NIF) and will provide a local, high-shot-rate facility for the LANL weapons-physics/ICF programs to prepare experimental concepts.

Inertial Confinement Fusion

The ICF program at Los Alamos is a principal component of the national ICF program, which is focused on the goal of achieving thermonuclear ignition of an inertially confined plasma in the laboratory. This national goal represents one of the grand scientific challenges of the 20th Century and supports the DOE Stockpile Stewardship Management Plan for nuclear weapons. In pursuit of the ICF mission, P-24 designs, diagnoses, executes, and analyzes the results from experiments in high-energy laser facilities worldwide. We team with theory and modeling efforts in other Laboratory divisions toward the ultimate goal of understanding laser/matter interaction physics.

NIF, a 1.8-MJ laser presently under engineering design, is the principal focus of the national ICF program. NIF is a flexible laser, expected to drive a capsule filled with deuterium-tritium (DT) fuel to thermonuclear ignition by two distinct methods, direct or indirect drive. In direct drive, the laser implodes the capsule by illuminating it directly. With indirect drive, the laser illuminates the interior walls of a cavity (called a hohlraum) that contains the capsule. The hohlraum walls convert the laser energy into x-rays, which illuminate the capsule very symmetrically, analogous to the process of baking an object evenly in an oven. Both direct and indirect drive have different potential failure modes, so the pursuit of both approaches increases the likelihood of achieving ignition at NIF. Considerable challenges will face us in operating NIF and in hastening the achievement of fusion. These include diagnostic development and improving our understanding in three main areas: laser-plasma instabilities, unstable hydrodynamics, and hohlraum dynamics. P-24 has made significant contributions in all three areas with experiments using present ICF lasers. P-24 is also a principal participant in the NIF Joint Central Diagnostic Team.

P-24 has made many important contributions to the national ICF target-physics program in support of NIF. We have devoted considerable effort to studying laser-plasma parametric instability processes. These instabilities pose an important threat to ignition hohlraums because they could potentially scatter most of the laser light, decreasing both the drive efficiency and the capsule-illumination symmetry. Our experiments have verified Los Alamos theoretical models, which predict quantitatively the onset of these instabilities in NIF-relevant conditions. We have also made important advances in establishing the mechanisms by which these processes saturate, the necessary first step before quantitative predictions and control of scattered-light levels are possible.

In support of these experiments, we have recently deployed at the Nova laser at Lawrence Livermore National Laboratory (LLNL) the world's best suite of optical diagnostics for ICF. These diagnostics can image the scattered light within the hohlraum, allowing unprecedented comparisons to theoretical models. P-24 has also done pioneering work in observations of previously unknown instability processes. Several P-24 researchers were part of the team recently recognized with a LANL Distinguished Performance Award for their prediction and direct observation of the deflection of a laser beam by a plasma flowing transverse to the beam-propagation direction.

P-24 research staff have made important contributions to the understanding of unstable hydrodynamics. For example, we have conducted experiments with novel cylindrically imploding targets. These targets allow study of nonlinear, multimode Rayleigh-Taylor (R-T) instability in convergent geometry, without the diagnostic access problems of spherical capsules. Another important successful line of our hydrodynamic research involves the use of gold-coated foams to minimize the imprint of laser nonuniformities in direct-drive targets early in the laser pulse. This imprint is a seed for hydrodynamic instabilities that degrade capsule performance. P-24 also remains in charge of fielding the collaborative LANL-LLNL experiments to benchmark our predictive capability of hohlraum dynamics and capsule illumination symmetry. In addition to fielding the experiments, we have helped develop and have validated the most successful symmetry diagnostic techniques (symmetry capsules and reemission balls).

AGEX: A Research-Based Approach to Science-Based Stockpile Stewardship

The AGEX team investigates the physics of high-energy-density matter in support of the national Stockpile Stewardship and Management Plan. We perform experiments in the areas of radiation-driven hydrodynamics (instability growth, shock propagation, and nonlinear hydrodynamics), radiation transport (opacity, atomic physics, and radiation flow), and material properties (equations of state and constitutive properties of materials). We actively develop and use state-of-the-art diagnostics, including x-ray and visible imaging, spectroscopy, interferometry, and radiography. Experiments on pulsed-power and laser systems are performed both at Los Alamos and at facilities worldwide (Trident, Pegasus II, PBFA-Z, Nova, and Omega) and will be continued on future planned facilities (NIF, Trident Upgrade, Atlas, and X1).

Present experiments include the study of the R-T instability growth in the nonlinear regime using ablative drive, propagation and stability of high-Mach-number perturbed shocks, opacity of open-M-shell atomic systems in local thermodynamic equilibrium (LTE), the study of Marshak waves in the subsonic and supersonic regimes, and equation-of-state measurements of low-Z and high-Z materials. Presently we are constructing a microchannel plate gated intensifier with an optical-gate width of 35 ps to 5 ns for x-ray imaging and spectroscopy and a high-resolution (~1 μm), one-dimensional x-ray imager, as well as other diagnostics. Our collaborators include LLNL, Sandia National Laboratories, the Atomic Weapons Establishment in England (AWE), and the Comissariat à l'Energie Atomique in France (CEA). We work closely with other programs, including the pulsed-power High-Energy-Density Physics and ICF programs.

Magnetic Confinement Fusion

The Magnetic Fusion Team in P-24 focuses on a variety of problems in controlling thermonuclear reactions in a laboratory, generally employing magnetic fields. The team is compact and our research projects are dynamic; these qualities allow us to maintain high visibility in the fusion community with high-quality research work. Our interests in plasma-confinement devices range from exotic alternates (including magnetized target fusion and inertial electrostatic fusion) to more conventional tokamaks, helical devices, and spheromaks. We collaborate experimentally with a number of facilities throughout the world, including JT-60U and LHD in Japan, the Alcator C-Mod tokamak at the Massachusetts Institute of Technology, the Tokamak Fusion Test Reactor (TFTR) and Feedback and Stability Experiment (FSX) tokamaks at Princeton University, the LSX-M Field Reversed Configuration at the University of Washington in Seattle, and the HBT-EP tokamak at Columbia University in New York City.

Our expertise lies in fast plasma diagnostics, neutron detection, high-speed visible and infrared (IR) imaging, plasma control, alternate confinement devices, and disruption studies. The LANL P-24 team has fielded high-power amplifiers to suppress magnetohydrodynamic (MHD) activity in plasmas and is collaborating with the Princeton Plasma Laboratory to scope out a so-called "smart shell" design for the newly proposed FSX tokamak at Princeton. Other off-site collaborations include IR imaging of tokamak diverters, triton burn-up studies in high-temperature deuterium plasmas, a variety of diagnostics on the high-power TFTR DT-plasma experiments, development of a prototype imaging bolometer, and fast imaging using a digital, high-speed, computer-controlled camera system and either periscopes or imaging bundles to view the plasmas. We have also participated in the Tokamak Physics Experimental design effort and are presently participating in the International Thermonuclear Experimental Reactor (ITER) design effort.

At Los Alamos, we have two confinement experiments in which we pursue fundamental fusion research. The first is called the Penning Fusion Experiment (PFX), which forms a spherical well using electrostatic and magnetic fields in a cryogenic trap. This experiment has demonstrated high electron densities and is working at inserting ions into the trap, which ultimately are of interest (and are necessary) for producing neutrons. Magnetized target fusion, or MTF, is our second area of research and involves the adiabatic compression of magnetized plasma to fusion conditions. Ongoing research within the Colt experiment is investigating target-plasma-formation techniques and heat transfer at high energy-density conditions.

Please visit our WWW site at http://wsx.lanl.gov for additional information.

Applied Plasma Technologies

The Applied Plasma Technologies Team in P-24 uses plasma science and technology to solve problems in defense, the environment, and industrial competitiveness. Major technology-development and program elements include the following:

Atmospheric-Pressure Plasma Jet (APPJ)

A nonthermal, uniform-glow discharge at atmospheric pressure in a cylindrical cavity with high gas-flow rates produces reactive radicals and metastable molecules persisting for fractions of a second at atmospheric pressure (Fig. I-10). These reactive species remove surface contaminants and films, providing a new means of cleaning objects and substrates. Current programs include removal of actinide and metallic contaminants, chemical decontamination for the neutralization of chemical agents on surfaces, and graffiti removal.

Intense, pulsed ion beams and accelerated plasmas

Several promising applications of intense ion beams and pulsed, accelerated plasmas that require repetitive beams and plasmas have emerged in the past few years. These include processing of materials, such as surface modification through rapid melt and resolidification, ablative deposition for producing high-quality coatings, and nanophase powder synthesis; production of intense neutral beams for the next generation of tokamaks; and intense, pulsed neutron sources for the detection of nonmetallic mines, neutron radiography, and spent nuclear fuel assay. We are developing a repetitive ion accelerator and an accelerated plasma source to investigate these applications.

Plasma-Source Ion Implantation (PSII) and cathodic arcs

PSII is a non–line-of-sight method for implanting ions from a plasma into a metal for surface modification. Typically, ions from a gaseous plasma are used, but cathodic arc technology allows metal ions to be implanted as well. PSII may be combined with plasma-based surface-coating technologies to form highly adherent, thick coatings of materials such as diamond-like carbon and ceramic metal oxides. Programs include plasma-implanted and plasma-deposited erbia coatings in support of the weapons surety program; molten-plutonium-resistant coatings for near-net-shape casting molds; highly adherent coatings for wear- and corrosion-resistant gun barrels for the Army; and plasma-based surface treatment and coatings for industrial tooling (this is part of a National Institute of Science and Technology [NIST] Advanced Technology Program with more than a dozen industrial partners).

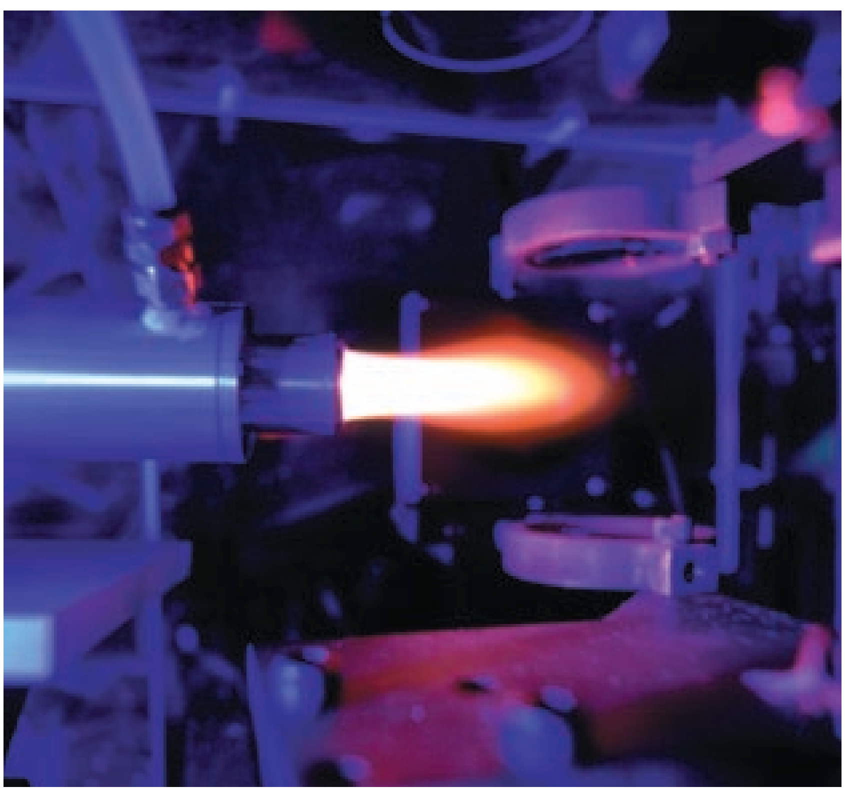


Fig. I-10. The atmospheric-pressure plasma jet has applications that include removal of actinide and metallic contaminants, chemical decontamination, and graffiti removal.